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Abstract: PURPOSE:The aim of this study was to evaluate magnetic resonance imaging (MRI) findings in cases of fatal manual or ligature strangulation. Verification of strangulation by computed tomography (CT), MRI, and at autopsy as well as its detectability in each modality was assessed. METHODS:We retrospectively analyzed 6 manual and ligature strangulation cases between 2013 and 2019 who all underwent a whole-body CT, head and neck MRI, and an autopsy. Two radiologists examined head and neck imaging data and compared the data to autopsy findings. RESULTS:Magnetic resonance imaging showed a high efficiency in verifying intramuscular hemorrhages, which were confirmed in autopsy. Moreover, in one case without a visible strangulation mark, soft tissue injuries associated with strangulation were detected. Fractures, especially thyroid cartilage fractures, were successfully diagnosed by CT. CONCLUSIONS:As MRI showed a successful detection of soft tissue lesions in relation to strangulation, it can serve as an alternative method or provide additional value to an autopsy. Intramuscular hemorrhages are a common finding in manual and ligature strangulation, providing a useful sign of applied pressure on the neck. However, to evaluate fractures, an additional CT or autopsy is recommended.

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Postmortem Magnetic Resonance Imaging and Postmortem Computed Tomography in Ligature and Manual Strangulation

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Purpose: The aim of this study was to evaluate magnetic resonance imaging (MRI) findings in cases of fatal manual or ligature strangulation. Verification of strangulation by computed tomography (CT), MRI, and at autopsy as well as its detectability in each modality was assessed.

Methods: We retrospectively analyzed 6 manual and ligature strangulation cases between 2013 and 2019 who all underwent a whole-body CT, head and neck MRI, and an autopsy. Two radiologists examined head and neck imaging data and compared the data to autopsy findings.

Results: Magnetic resonance imaging showed a high efficiency in verifying intramuscular hemorrhages, which were confirmed in autopsy. Moreover, in one case without a visible strangulation mark, soft tissue injuries associated with strangulation were detected. Fractures, especially thyroid cartilage fractures, were successfully diagnosed by CT.

Conclusions: As MRI showed a successful detection of soft tissue lesions in relation to strangulation, it can serve as an alternative method or provide additional value to an autopsy. Intramuscular hemorrhages are a common finding in manual and ligature strangulation, providing a useful sign of applied pressure on the neck. However, to evaluate fractures, an additional CT or autopsy is recommended.

Key Words: manual strangulation, ligature strangulation, magnetic resonance imaging, forensic radiology, virtopsy

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KEY POINTS

1. Magnetic resonance imaging findings were evaluated in cases of fatal manual and ligature strangulation
2. The majority of ligature and manual strangulation cases showed intramuscular hemorrhage in the ventral neck musculature
3. Intramuscular hemorrhages are the most prominent collateral injury in cases of ligature and manual strangulation

Most data about injuries in strangulation are obtained from hanging.[1–3] Certain characteristic traumatic injuries have been described throughout the years. Laryngeal fractures are a common injury in addition to soft tissue lesions, such as subcutaneous, intramuscular, and lymph node, and glandular hemorrhages and swellings.[4–6] Intramuscular hemorrhages are an important sign of strangulation, and other tissue alterations, such as lymph node swellings or lung and soft tissue emphysema, can be found in the literature but are not reliable in proving vitality (vital signs) at the time of the incident.[7–9] Hanging is frequently related to suicide, whereas suicides by ligature strangulation are rarely described,[1,10] and suicide by manual strangulation is not feasible.[11,12] Both manual and ligature strangulation can cause an interruption of blood flow, especially with increased pressure on the jugular veins. Subsequent oxygen deprivation of vitally important brain regions leads to death.[1,13,14] During the process of strangulation, neck injuries occur frequently, which can be visualized by computed tomography (CT), magnetic resonance imaging (MRI), or autopsy.[3,15–19] According to these studies, intramuscular hemorrhages and subcutaneous bleeding are considered important indicators of severity. In those studies, MRI showed a significant value in detecting these injuries.[4,15,19] However, postmortem imaging of ligature and manual strangulation has been described mainly in CT and x-ray, focusing on laryngeal lesions and subcutaneous hemorrhages.[20,21] Only a small case study analyzing MRI in fatal manual strangulation was presented by Yen et al[22] almost 15 years ago. According to Yen et al,[22] the main findings in fatal manual strangulation were lymph node and intramuscular hemorrhages. No studies can be found in the literature regarding ligature strangulation on MRI.[3]

In our study, we describe 6 individuals who died of ligature and manual strangulation who underwent a whole-body CT, neck and head MRI, and an autopsy. In addition to CT, we analyzed all MRI examinations focusing on hemorrhages. The presence of skull, cervical spine, and laryngeal fractures as well as previously described fracture-related gas bubbles were assessed on CT.[3,23] In addition, we evaluated brain hemorrhages and brain edema on both modalities, which were deemed a potential indicator for the severity of premortal damage.[24] For a complete overview, we verified the presence of soft tissue and lung emphysema as well as pneumomediastinum on CT.[8,25,26]

MATERIALS AND METHODS

Individuals who died from manual and ligature strangulation between 2013 and 2019 who all underwent a whole-body CT, head and neck MRI, and an autopsy were analyzed retrospectively. Case-related data, including the strangulation mechanism, external corporal findings, date of incident, discovery, and death, were retrieved.

Computed Tomography

All decedents underwent a whole-body CT and a separate head and neck CT. A 128-slice CT scanner (Somatom Definition Flash; Siemens Healthcare, Forchheim, Germany) was used. All scans were performed before autopsy using 120 kV and automatic dose modulation (CARE Dose4DTM; Siemens, Forchheim,

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Ethical approval: This study was performed with human cadavers. This article does not contain any studies with (living) human participants or animals performed by any of the authors. The scan data were acquired as part of a forensic judicial investigation. That data usage is conformant with Swiss laws and ethical standards as approved by the Ethics Committee of the Canton of Zurich (written approval, KEK ZH-Nr. 2015-0686).

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Germany) with a reference value of 800 mAs. The head and neck region was reconstructed with a slice thickness of 0.6 mm in an adjusted field of view (<300 mm). The thorax and abdominal region was reconstructed with a slice thickness of 1 mm. An additional high-resolution scan of the larynx region was performed and reconstructed with a slice thickness of 0.4 mm.

Magnetic Resonance Imaging

Magnetic resonance imaging was performed using a 3-T whole-body scanner (Achieva; Philips Healthcare, Best, the Netherlands). T1-weighted (echo time TE, 8 miliseconds repetition time [TR], 562 milliseconds), T2-weighted (TE, 100 milliseconds; TR, 3935 milliseconds), T2*, if applied, (TE, 16 miliseconds, TR, 1015 miliseconds) and T2-weighted short-TI inversion recovery (STIR; inversion time [TI], 190 milliseconds; TE, 60 milliseconds; TR, 6468 milliseconds) sequences were performed in axial orientation with a slice thickness of 3 mm.

Radiological Assessment

Two radiologists evaluated all images retrospectively, and discrepancies were discussed with the goal of achieving concordance. Predetermined findings were the presence of a strangulation mark, laryngeal fractures, skull and cervical spine fractures, the gas bubble sign,[23] hemorrhages and brain edema, and brain hemorrhages. The thorax and abdomen CT images were assessed concerning lung and soft tissue emphysema.

Autopsy

In each case, a resident, a board-certified forensic pathologist and an autopsy technician performed the autopsy. Computed tomography and MRI findings were communicated to the forensic pathologists before the onset of autopsy. Autopsy findings were retrospectively extracted from reports.

RESULTS

Case Histories and Expert Opinions

We analyzed 6 cases (ligature strangulation n = 3, manual strangulation n = 3) with an average estimated postmortem interval of 41 hours from death to autopsy (range, 17–106 hours). Computed tomography, MRI, and autopsy all took place within 24 hours in all cases. An overview of all results can be found in Table 1.

TABLE 1. Overview of Case Details and Findings on CT, MRI, and AUT

Case	1	2	3	4	5	6
Age, y	41	36	23	28	93	78
Sex	M	F	F	M	F	M
Manual strangulation	−	+	+	−	+	−
Ligature material	Cable			Cable		Scarf
Hyoid fracture						
AUT	+	−	−	−	−	−
CT	+	−	−	−	−	+
MRI	−	−	−	−	−	−
Thyroid fracture						
AUT	+	+	−	−	+*	+
CT	+	+	−	−	+*	+
MRI	−	−	−	−	−	−
Intramuscular hemorrhage						
AUT	VNM	SCM	SHM	GHM	−	−
CT	Swelling	−	Swelling	Swelling	−	−
MRI	VNM	SCM	SHM	GHM	−	SCM

Intramuscular hemorrhages were detected in more than one ventral neck muscle and in sternocleidomastoid, sternohyoid, and geniohyoid muscle. In case 5 at autopsy, a fresh fracture of the thyroid cartilage was observed, whereas on CT, old sclerotized fractures were found (marked with an asterisk). AUT, autopsy; VNM, ventral neck muscle.

Case 1

A 40-year-old imprisoned man was found alone in the middle of a room with a cable wrapped around his neck. The ligature had no contact with any furniture or the walls of the room. A bottle of shaving foam acting as a lever was fixed in a loop and tied up with knots between his neck and chest. The cable was turned consecutively, increasing the pressure on the neck until the blood flow was interrupted. At external inspection, prominent signs of congestion were noted. Self-strangulation was declared.

Case 2

A 36-year-old woman was discovered in a lake floating with bound hands. Her body showed several hematomas with signs of blunt force. Several hematomas consistent with manual strangulation, especially on her ventral neck and submandibular regions, were documented. The autopsy did not reveal typical signs of drowning such as lung emphysema, edema aquosum, or elevated organ weights, but neck injuries, that is, a laryngeal fracture, were consistent with strangulation. Toxicology results were negative regarding medications or drugs. Considering all findings and the event-related circumstances, the forensic pathologists declared death by manual strangulation.

Case 3

A 22-year-old woman was manually strangled. The offender alarmed the neighbors who notified the police and called for an ambulance. Although a resuscitation attempt was initially successful, because of an unfavorable prognosis, the relatives approved a discontinuation of treatment approximately 36 hours after the incident. At the external examination, the face of the decedent showed several subcutaneous hematomas consistent with blunt force. At the neck, streaks of subcutaneous hemorrhages were found ventrally and laterally, consistent with strangulation. Moreover, a hyperdistended lung and pleural petechial hemorrhages were found later at autopsy. Together with the external and radiologic findings, death by manual strangulation was defined, which was consistent with the statements of the accused who described how he strangled her.

Case 4

A 28-year-old man was found in an incomplete typical hanging position with severe cranial blunt trauma. The accused stated that he first beat the man's head with a hammer and strangled him and then took him into another room where he finally hanged the stertorous breathing man as described previously. The radiologic signs of aspiration on CT, as well as intramuscular hemorrhages in the neck, were found later on MRI, indicating that the man was still alive when he was hung. Thus, the severe cerebral trauma, ligature strangulation, and hanging were deemed a fatal combination.

Case 5

A 93-year-old woman was found lying in her bed. She was multimorbid and immobile. The bedroom window was open, and a lamp laid on the floor. The body's surface showed fresh hematomas of the skin at her cheeks, neck and jaws, as well as several hematomas on the upper limbs, which raised suspicion

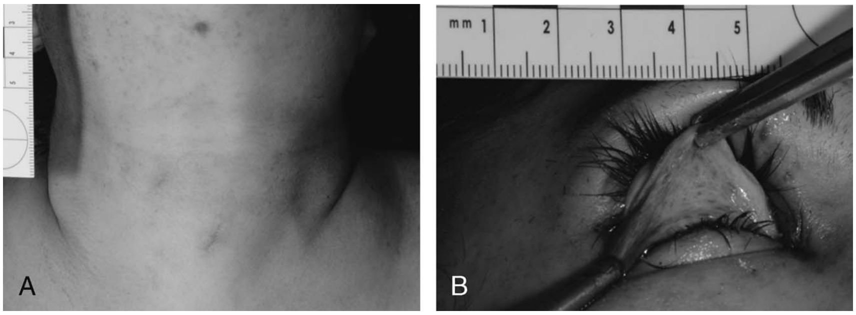

FIGURE 1. External examination showed typical cutaneous hematomas (A) and petechial bleeding (B) by fatal manual strangulation in case 3.

of manual strangulation. Autopsy revealed age-related organ alterations such as brain atrophy, chronic inflammation of the airways, and kidney atrophy. There were no indications of acute organ failure implicating a natural cause of death. In contrast, the autopsy and histologic examinations confirmed fresh injuries at the neck and in the soft tissue of the face. Moreover, the results of the toxicological examination were negative. Foreign DNA was found on her neck and cheeks. According to the relevant findings, fatal strangulation was strongly implicated.

Case 6

It was assumed that a 78-year-old man who was under psychiatric treatment strangulated himself during an unwatched period using a scarf. He was found lying on the floor by the nursing staff. The patient was unconscious. After an initially successful resuscitation, he died 2 days later in the hospital because of severe brain damage. A local doctor conducted an external examination. Afterwards, the decedent was transferred to our institute to confirm suicide and suspicion for self-strangulation. The initial event was not photographically documented; thus, the finding situation and the strangulation mechanism could not be well assessed. Nevertheless, suicidal ligature strangulation was deemed consistent with the findings of an external re-examination. Despite a lack of superficial strangulation marks, autopsy and imaging revealed intramuscular hemorrhages on the neck as well as a fractured superior cornu of the thyroid cartilage.

Postmortem Imaging and Comparison With Autopsy

In all cases, hematomas consistent with manual strangulation or strangulation marks of the ligature were identified. Furthermore, petechial bleeding and hematomas were visible in all cases (Fig. 1). For ligature strangulation, cables were used in cases 1 and 4, and in case 6, a scarf was used as the strangulation tool.

Muscle Hemorrhages

Cases 1, 3, and 4 demonstrated swelling of the neck muscles on CT. In 4 cases, an intramuscular hemorrhage was diagnosed on MRI and at autopsy in the same group of muscles (cases 1–4). In case 6, a discrete hemorrhage in the sternocleidomastoid muscle

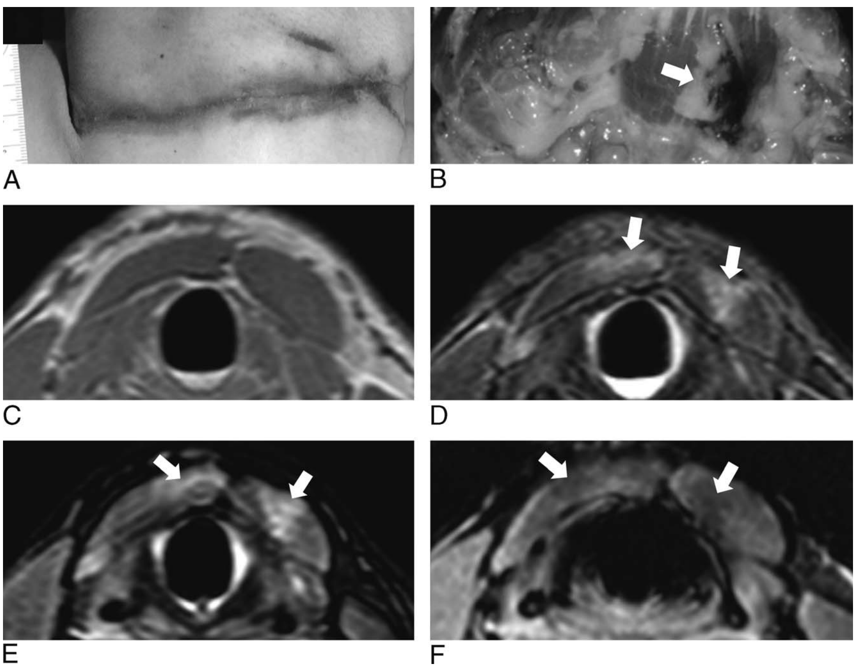

FIGURE 2. Case 4: Strangulation mark on the skin of the neck (A), intramuscular hemorrhage consisting of the strangulation mark, and the imaging results at the autopsy (B). MRI revealed intramuscular hemorrhage in the sternohyoid muscles with no signal alteration on the T1-weighted image (C), hyperintense signals (arrows) on T2 images (D) and the STIR sequence (E), and a corresponding hypointense signal on the T2* images (F).

was suspected on MRI but could not be confirmed at autopsy. Only case 5 did not show any hemorrhaging in any diagnostic modality. Primary sites for muscle hemorrhages were the sternocleidomastoid muscle and sternohyoid muscle (Fig. 2). One case showed bleeding in the geniohyoid muscle.

Laryngeal Fractures

In 4 cases, laryngeal fractures occurred. In 3 cases (1, 2, and 6), an acute/fresh thyroid fracture was diagnosed on CT and confirmed at autopsy. Case 1 also showed gas bubbles near the thyroid fracture. In case 5, an old sclerotized fracture of the middle part of the thyroid cartilage was detected on CT, whereas in autopsy, a fresh fracture of the superior cornu was reported. Three of the 4 cases with thyroid fractures were cases of ligature strangulation. In case 1, an additional fracture of the hyoid bone was detected on CT as well as at autopsy (Fig. 3). In case 6, an impression fracture of the hyoid was suspected on CT but could not be confirmed at autopsy. Magnetic resonance imaging did not show any fractures. No cricoid fractures were detected.

Skull and Cervical Spine Fractures

In cases 1 and 4, a skull fracture was diagnosed on CT and at autopsy and on MRI in case 4. Case 1 showed a fracture of the temporal bone compatible with a drop to the floor or seizure-related

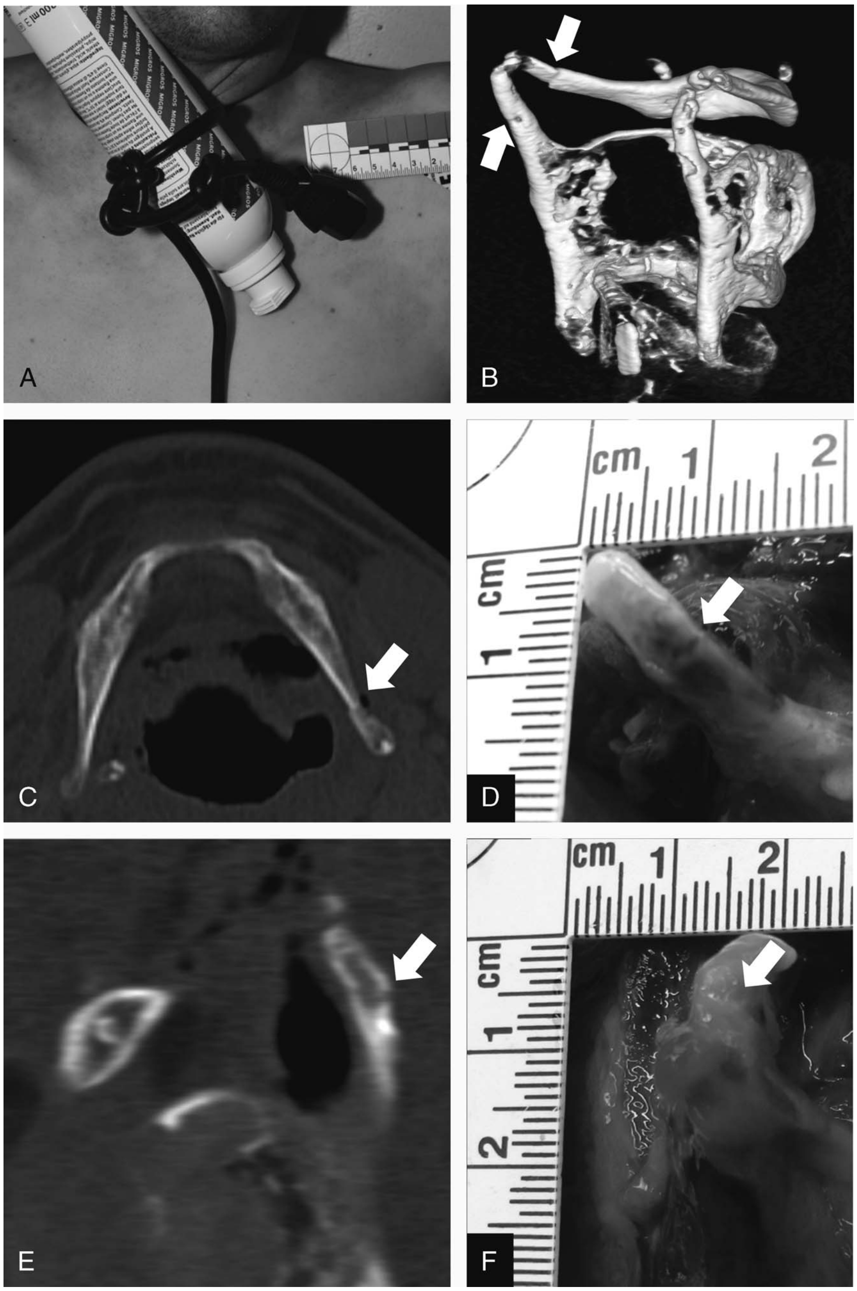

FIGURE 3. Case 1 used a cable and a can for self-strangulation (A). His hyoid bone and thyroid cartilage showed fractures (arrows) on CT 3-dimensional volume rendering (B) on the axial CT image (C), and a fracture of the left cornu was detected at autopsy (D). The fracture of the left superior cornu in a sagittal CT image (E) and at autopsy (F).

trauma in the process of self-strangulation. Case 4 showed multifragmented and dislocated fractures of the frontal, parietal, temporal, and occipital bone in accordance with the described fight. No cervical spine fractures were detected.

Lymph Node Hemorrhage and Swelling

No lymph node hemorrhages were detected. However, a lymph node swelling was visible in cases 1 and 3 on CT, and in case 4 on MRI, the diameter was just greater than 1 cm. At autopsy, lymph node swelling was not documented in any case. In all cases, the morphologic structure of the lymph nodes did not show any signs of suspected alterations or malignancy.

Brain Edema and Hemorrhages

The detection of brain edema revealed discrepancies between CT and autopsy. Computed tomography showed brain edema in cases 2, 3, 4, and 6, whereas edema was noted at autopsy in cases 3 and 1. Magnetic resonance imaging did not show brain edema in any case. In 2 of our cases, a brain hemorrhage occurred (cases 1 and 4) perifocal to the traumatic bone fractures.

Lung Emphysema

In cases 1 and 5, lung emphysema was detected on CT; however, the emphysema in case 5 had been reported antemortem according to medical records.

DISCUSSION

This study shows the value of MRI in detecting soft tissue injuries caused by the strangulation process in manual and ligature strangulation.

All but one documented hemorrhage were diagnosed on MRI and confirmed at autopsy. The unconfirmed hemorrhage occurred in a decedent who died a week after the incident. Therefore, we assume that the hyperintensive T2 and STIR signals originated from posttraumatic fluid accumulations as a collateral result of ruptures of the muscle fibers. The ventral neck muscles appear to be the main site of hemorrhage. These findings are in accordance with the described injuries in victims of manual strangulations from Yen et al.[22] As we detected intramuscular hemorrhages in every case but one on MRI, which were confirmed at autopsy, MRI can be considered a reliable tool to visualize such injuries.

Magnetic resonance imaging aids in the diagnosis of vital signs in fatal hanging cases by detecting intramuscular hemorrhages, as described in the literature.[3] In this retrospective study, the dimensions of the lesions on radiological data were not compared with the findings at autopsy, since we did not have any autopsy data about these specific details.

Technically, the combination of T1, T2, and STIR MRI sequences was sufficient to diagnose soft tissue injuries, including intramuscular hemorrhages, in cases with a short time interval

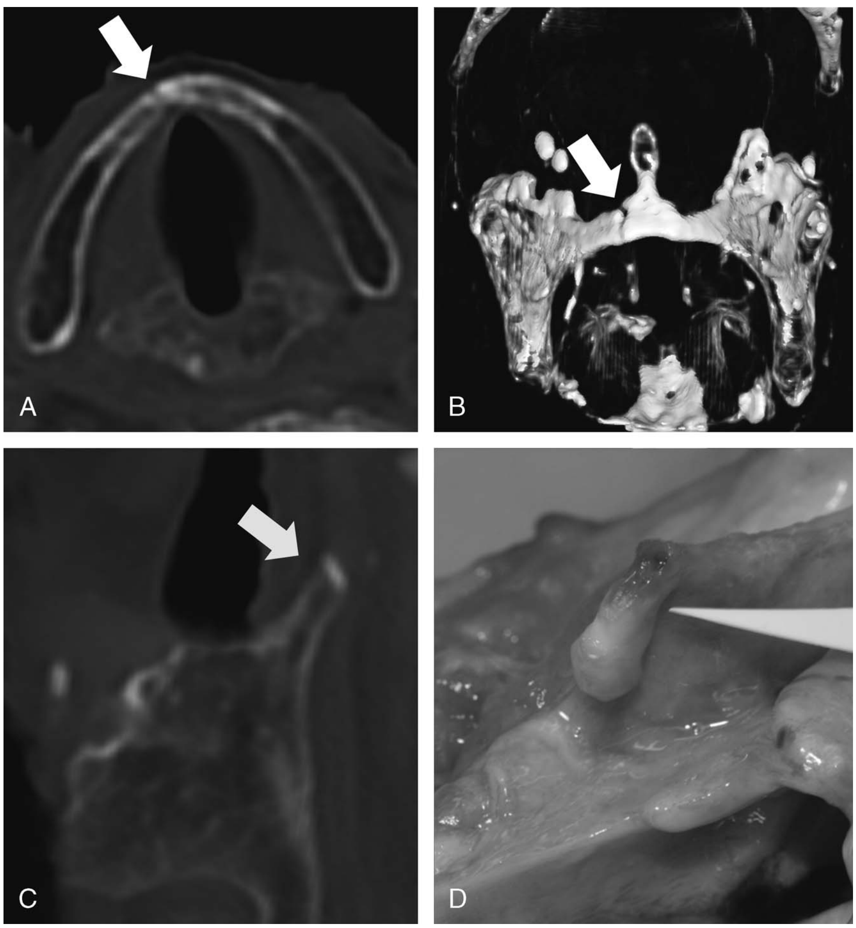

FIGURE 4. Case 5: An old sclerotized fracture (arrow) was diagnosed on axial CT images (A) and on 3D volume rendering (B). A fresh fracture of the superior cornu of the thyroid was missed on the CT scan (yellow arrow) as it occurred in the nonsclerotized portion (C). At autopsy, the fracture was clearly identifiable (D).

between the incident and imaging. In cases such as case 6, an additional MRI sequence, such as gradient echo sequences (T2*), is necessary to differentiate between hemorrhages and edema. With regard to the STIR sequence, it must be considered that the TI of fat and water, and hence their saturation, can be variable due to lower body temperature. Changes in longitudinal relaxation time (T1) can influence the appropriate TI, which can lead to an inefficient suppression of fat.[27]

Regarding cartilage and bone fractures of the laryngeal skeleton, a discrepancy between CT and autopsy was observed. A fresh fracture of the superior cornu of the thyroid was missed on CT; however, it occurred in a noncalcified part where the contrast is minor. In the same decedent, an old sclerotized fracture was detected on CT but not at autopsy because no instability or any perifocal hemorrhage was present and therefore did not raise any suspicion (Fig. 4). In case 6, a suspected hyoid fracture on CT was not confirmed at autopsy. After a second radiologic assessment, the cortical irregularity described on CT was deemed rather unspecific, and no clear delineation of the fracture line was visible. It was possible that an old healed fracture caused the inhomogeneous shape of the hyoid. Although the hyoid bone was unfractured, the fracture of the superior thyroid cornu indicated applied forces against the neck. We are aware that this case cannot be declared as self-strangulation with absolute certainty, although we cannot disprove the initial suspicion either. All previous described findings are consistent with possible self-strangulation.[28]

The detection of lymph nodes revealed only vague and variable results. We did not observe any hemorrhaging; however, we did note unspecific and discrete swellings, but we cannot exclude a possible infectious background for those. Similar to lung emphysema, the impact of preexisting parenchymal alterations must be considered.

Overall, MRI can be useful to specify injuries resulting from manual or ligature strangulation, as it is an excellent tool for detection and diagnosis, especially for soft tissue lesions.

Despite the small number of cases, this study is, to the best of our knowledge, the first documentation of MRI findings in fatal ligature strangulation. The detectability of relevant findings in strangulation cases using CT and MRI was presented. However, as it was a retrospective study, the autopsy findings in particular could not be reevaluated, and thus, the comparison of autopsy and imaging findings was limited. Moreover, forensic pathologists were not blinded to the imaging results at the time of the autopsy, in contrast to the radiologic reviewers. To assess the sensitivity of MRI and CT compared with autopsy, a blinded prospective study including more cases is desired.

CONCLUSIONS

This study demonstrated the use of CT and MRI in cases with ligature and manual strangulation and showed the benefit of an MRI examination in suspicious cases, such as case 5, to prove soft tissue lesions indicating fatal strangulation. To evaluate fractures, an additional CT is necessary; however, a special MRI sequence may overcome this limitation in the future. Further studies are required to assess these imaging modalities as potential alternatives to autopsy in certain cases.

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